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Title: SILICON-GERMANIUM ETCH STOP LAYER SYSTEM

Abstract

A SiGe monocrystalline etch-stop material system on a monocrystalline silicon substrate. The etch-stop material system can vary in exact composition, but is a doped or undoped $Si_{1-x}Ge_x$ alloy with x generally between 0.2 and 0.5. The etch-stop of the invention includes the use of a graded-composition buffer between the silicon substrate and the uniform SiGe etch-stop material. Nominally, the buffer has a linearly-changing composition with respect to thickness, from pure silicon at the substrate/buffer interface to a composition of germanium, and dopant if also present, at the buffer/etch-stop interface which can still be etched at an appreciable rate. Here, there is a strategic jump in germanium and concentration from the buffer side of the interface to the etch-stop material, such that the etch-stop layer is considerably more resistant to the etchant. The etch-stop is used for micromachining by aqueous anisotropic etchants of silicon such as potassium hydroxide, sodium hydroxide, litium hydroxide, ethylenedi-amine/pyrocatechol/pyrazine (EDP), TMAH, and hydrazine.
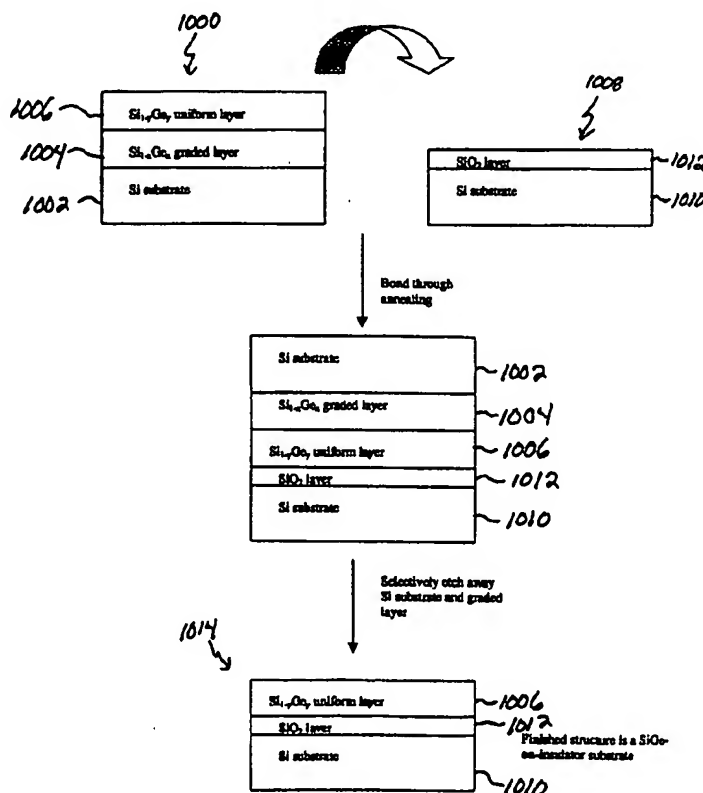
SILICON-GERMANIUM ETCH STOP LAYER SYSTEM

PRIORITY INFORMATION

This application claims priority from provisional application Ser. No. 60/081,301 filed

5   April 10, 1999.

BACKGROUND OF THE INVENTION

The invention relates to the field of etch-stop material systems on monocrystalline silicon.

Microelectromechanical systems (MEMS) form the bridge between conventional

10   microelectronics and the physical world. They serve the entire spectrum of possible applications.

MEMS include such varied devices as sensors, actuators, chemical reactors, drug delivery

systems, turbines, and display technologies. At the heart of any MEMS is a physical structure (a

membrane, cantilever beam, bridge, arm, channel, or grating) that is "micromachined" from silicon

or some other electronic material. Since MEMS are of about the same size scale and, ideally,

15   fully integrated with associated microelectronics, naturally they should capitalize on the same

materials, processes, equipment, and technologies as those of the microelectronics industry.

Because the process technology for silicon is already extensively developed for VLSI electronics,

silicon is the dominant material for micromachining. Silicon is also mechanically superior to

compound semiconductor materials and, by far, no other electronic material has been as

20   thoroughly studied.

A wide array of micromachined silicon devices are fabricated using a high boron

concentration "etch-stop" layer in combination with anisotropic wet etchants such as

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ethylenediamine and pyrocatechol aqueous solution (EDP), potassium hydroxide aqueous solution

(KOH), or hydrazine (N_2H_2). Etch selectivity is defined as the preferential etching of one

material faster than another and quantified as the ratio of the faster rate to the slower rate.

Selectivity is realized for boron levels above 10^{19} cm^{-3}, and improves as boron content increases.

5   It should be noted that etch stops are also used in bond and etch-back silicon on insulator

(BESOI) processing for SOI microelectronics. The etch-stop requirements differ somewhat from

those of micromachining, e.g., physical dimensions and defects, but the fundamentals are the

same. Hence, learning and development in one area of application can and should be leveraged in

the other. In particular, advances in relaxed SiGe alloys as substrates for high speed electronics

10   suggests that a bond-and-etch scheme for creating SiGe-on-insulator would be a desirable process

for creating high speed and wireless communications systems.

SUMMARY OF THE INVENTION

        Accordingly, the invention provides a SiGe monocrystalline etch-stop material system on a

15   monocrystalline silicon substrate. The etch-stop material system can vary in exact composition,

but is a doped or undoped $Si_{1-x}Ge_x$ alloy with x generally between 0.2 and 0.5. Across its

thickness, the etch-stop material itself is uniform in composition. The etch stop is used for

micromachining by aqueous anisotropic etchants of silicon such as potassium hydroxide, sodium

hydroxide, lithium hydroxide, ethylenediamine/ pyrocatechol/ pyrazine (EDP), TMAH, and

20   hydrazine. For example, a cantilever can be made of this etch-stop material system, then released

from its substrate and surrounding material, i.e., "micromachined", by exposure to one of these

etchants. These solutions generally etch any silicon containing less than 7×10^{19} cm^{-3} of boron or

undoped $Si_{1-x}Ge_x$ alloys with x less than approximately 18.

Alloying silicon with moderate concentrations of germanium leads to excellent etch selectivities, i.e., differences in etch rate versus pure undoped silicon. This is attributed to the change in energy band structure by the addition of germanium. Furthermore, the nondegenerate

5   doping in the $Si_{1-x}Ge_x$ alloy should not affect the etch-stop behavior.

The etch-stop of the invention includes the use of a graded-composition buffer between the silicon substrate and the SiGe etch-stop material. Nominally, the buffer has a linearly-changing composition with respect to thickness, from pure silicon at the substrate/ buffer interface to a composition of germanium, and dopant if also present, at the buffer/ etch-stop interface

10   which can still be etched at an appreciable rate. Here, there is a strategic jump in germanium and concentration from the buffer side of the interface to the etch-stop material, such that the etch-stop layer is considerably more resistant to the etchant.

In accordance with one embodiment of the invention, there is provided a monocrystalline etch-stop layer system for use on a monocrystalline silicon substrate, the system comprising a

15   graded layer of $Si_{1-x}Ge_x$ and a uniform etch-stop layer of $Si_{1-y}Ge_y$. In a particular embodiment, the buffer layer is graded up to approximately $Si_{0.8}Ge_{0.2}$ and a uniform etch-stop layer of approximately $Si_{0.7}Ge_{0.3}$.

In another embodiment of the invention, there is provided a method of fabricating a monocrystalline etch-stop layer on a silicon substrate comprising depositing a graded buffer layer

20   of $Si_{1-x}Ge_x$ on the silicon substrate; and depositing a uniform etch-stop layer of $Si_{1-y}Ge_y$ on the graded buffer layer. In a particular embodiment, the buffer layer is graded up to approximately $Si_{0.8}Ge_{0.2}$ on the silicon substrate; and the uniform etch-stop layer of $Si_{0.7}Ge_{0.3}$ is deposited on the

graded buffer layer.

In yet another embodiment of the invention, there is provided a method of micromachining an integrated device comprising providing a silicon substrate; depositing a graded buffer layer of $Si_{1-x}Ge_x$ on the silicon substrate; depositing a uniform etch-stop layer of $Si_{1-y}Ge_y$ on the graded

5   buffer layer; etching portions of the silicon substrate and the graded buffer layer in order to release the etch-stop layer; and processing the released etch-stop layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGs. 1A-1D are functional block diagrams of exemplary epitaxial SiGe etch stop

10   structures configured on a silicon substrate in accordance with the invention;

FIG. 2 is a cross-sectional TEM micrograph of the structure of FIG. 1B;

FIG. 3 is a cross-sectional TEM micrograph of the structure of FIG. 1C;

FIG. 4 is graph of dopant concentrations of the structure of FIG. 1A;

FIG. 5 is a graph of dopant concentrations of the structure of FIG. 1D;

15   FIG. 6A is a graph showing the cylindrical etch results of the structure of FIG. 1A; FIG.

6B is graph showing a magnification of the left side of FIG. 6A;

FIG. 7 is a graph showing the cylindrical etch results of the structure of FIG. 1D;

FIG. 8 is a graph showing the etch rates for <100> intrinsic silicon in 34% KOH at 60°C

normalized by 18.29 µm/hr of the structures of FIGs. 1A-1D;

20   FIG. 9 is a photograph of a top view of a micromachined proof mass; and

FIG. 10 is a block diagram of a process for fabricating an SiGe-on-insulator structure.

DETAILED DESCRIPTION OF THE INVENTION

In the traditional method of forming etch stops in Si micromachining or in certain SOI

processes, good etch-stop results are only obtained at very high concentrations of boron, and the

dopant's effect on the silicon crystal structure becomes vitally important. Substitution of a silicon

5   atom site with boron, a smaller atom than silicon, contracts the silicon lattice. As the doped

lattice remains coherent with the lattice of the undoped substrate, a biaxial "lattice mismatch"

stress is generated in the plane of the substrate. This stress biaxially elongates, i.e., elastically

strains, the doped material in the same plane. As the base of a unit cell is strained, so is the height

via Poisson distortion. Therefore, the Si:B lattice is vertically contracted as it is horizontally

10   expanded, leading to a smaller vertical lattice constant than the equilibrium value. For thin layers

of Si:B, it is energetically favorable for the material to be elastically strained like this, i.e.,

"pseudomorphic".

As the thickness of the doped layer grows, however, the total strain energy per unit area

of film increases proportionally, until the layer surpasses a "critical thickness" when it is

15   energetically favorable to introduce dislocations instead of elastically straining the film.

Dislocation loops are heterogeneously nucleated at the film surface or film edges and grow larger,

gliding towards the substrate-film interface. When a loop meets the interface, the two ends (now

called "threading" dislocations because they traverse the thickness of the film) continue to travel

away from each other, trailing a line defect at the interface known as a "misfit" dislocation. The

20   misfit dislocations accommodate the lattice-mismatch stress, relieving the horizontal and vertical

strains and restoring the in-plane and perpendicular lattice constants to the equilibrium value, i.e.,

"relaxing" the material. For a low-mismatched lightly strained epitaxial film on a diamond cubic

or zincblende substrate, a mesh of orthogonal <110> misfit dislocations is the most likely configuration because of the {111}<110> easy slip system for these crystal structures at elevated temperatures, such as those involved in diffusion and most CVD processes.

At high enough quantities, the effects of any dissimilar-sized substitutional atom on the silicon microstructure are the same as those of boron. Of course, the impact depends on the relative size and concentration of the substitutional species. Also, incorporation of a larger atom than silicon, e.g., germanium, would result in compressive stress and strain rather than a tensile situation like Si:B.

In the conventional etch stop process, extremely high concentrations of boron are needed to achieve a high etch rate selectivity. These very high boron concentrations lead to dislocation introduction in the thick films that are desired in many MEMS applications. Since the p++ process is created usually through a diffusion process, there is a gradient in dislocation density and a gradient in the boron concentration. Because the etch stops in the boron concentration gradient, the thin film part typically possesses large curvature, which is compensated for by an annealing treatment. In addition, the etch stop selectivity is extremely sensitive to the boron concentration. If the concentration falls below the critical $7x10^{19}cm^{-3}$, the selectivity is drastically different. Thus, since this boron concentration is near the solubility limit, dopant concentration fluctuations in the vertical and lateral dimensions produce low yields in MEMS processes. The SiGe etch stop breaks the link between dopant concentration and etch selectivity. Also, since the SiGe alloy is a miscible alloy system, there is continuous complete solubility between Si and Ge.

The theory of anisotropic etching of silicon as described by Seidel et al., J. Electrochem. Soc. 137 , pp. 3626-31 (1990), incorporated herein by reference, is widely considered the

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appropriate model. Although specifics like absolute etch rate and dissolution products may differ, the general concept is valid for all anisotropic etchants, as they are all aqueous alkaline solutions and the contribution of the etchant is modeled as nothing more specific than H_2O and OH^-. Indeed, the existing literature shows consistent behavior among the etchants.

5   Early work on etch rate reduction in p++ Si:B presented no hypotheses beyond empirical data. Two possible explanations for the etch-stop phenomenon were proposed: stronger bonding from the high boron concentration or the formation of a boron-based passivation layer. As research accumulated, the etch-stop theories aligned along two credible approaches. The electronic models assign etch-stop behavior to the action of carriers while the passivation models

10   directly attribute it to the formation of a passivating oxide-based layer on the silicon surface.

Others concluded that the etch-rate decrease is sensitive to hole concentration and not to atomic concentration of boron or stress. They observed an etch rate drop that was proportional to the fourth power of the increase in boron concentration beyond about 3×10^{19} cm^{-3}. Four electrons are required by a red-ox etching process they described, leading them to explain the

15   etch-stop effect in p++ material as an increased probability that the electrons are lost to Auger recombination because of the higher hole concentrations.

Seidel et al. agreed with the electron recombination hypothesis. They saw the etch rate begin to fall around 2-3×10^{19} cm^{-3}, which agrees with the doping level for the onset of degeneracy, 2.2×10^{19} cm^{-3}. At degeneracy, the Fermi level drops into the valence band and the

20   band-bending is confined to a thickness on the order of one atomic layer. The injected electrons needed for etching are able to tunnel through such a narrow potential well and recombine in the p++ bulk crystal, which halts the etching reaction. The remnant etch rate in the etch-stop regime

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is attributed to the conduction band electrons, whose quantity is inversely proportional to the

hole, i.e. boron, concentration. Four electrons are required to etch one silicon atom, which

explains the dependence of the remnant etch rate on the fourth power of the boron concentration.

It was observed that the formation of an SiO_x passivation layer on p++ $Si:B(2x10^{20}cm^{-3})$

5   in aqueous KOH by *in situ* ellipsometric measurements. In the case of p^+ -Si, a large number of

holes at the surface causes spontaneous passivation with a thin oxide-like layer. The layer is not

completely networked like thermal oxide, so it is etched faster and there is still transport of

reactants and etch products across the layer, leading to some finite overall etch rate. The lattice

strain induced by a high dopant concentration could enhance the layer's growth. Furthermore, the

10   etch rate reduction is not a Fermi-level effect since the phenomenon is exhibited by both heavily

doped p- and n-silicon.

Chen et al., J. Electrochem. Soc. 142, p.172 (1995), assimilated the observations and

hypotheses above and their own findings into a composite electrochemical model, where etch

stopping is attributed to the enhancement of the oxide film growth rate under high carrier

15   concentration. The key process is hole-driven oxidation at the interface, which inhibits etching by

competing with a reaction for Si-Si bonds and hydroxyl radicals, but more importantly, by

building the SiO_x barrier. In p++ silicon, a sufficient quantity of holes for etch-stop behavior is

supplied as the converse of the electron action outlined by Seidel et al. That is, instead of

electrons thermally escaping the potential well or tunneling through into the bulk crystal, holes

20   from the bulk crystal thermally overcome or tunnel through the potential barrier to the interface.

It will be appreciated that this etch-stop process is dynamic, i.e., it is a continuous competition of

silicon dissolution and formation/ dissolution of the oxide-like layer, whose net result is a nonzero

etch rate.

Germanium is appealing as an etch-resistant additive because it is isoelectronic to, and perfectly miscible in, silicon and diffuses much less readily than dopants and impurities in silicon. Furthermore, the epitaxy of silicon-germanium alloys is selective with respect to silicon oxide,

5   facilitating patterning and structuring, and even affords higher carrier mobilities to electronics monolithically integrated with MEMS.

Existing germanium-based etch-stop systems are, at best, only marginally suitable for silicon micromachining. In spite of the aforementioned advantages to using germanium, currently there is an inadequate understanding of the etch-stop effect in silicon-germanium materials and no

10   information on anisotropic etching of high germanium content solid solutions.

Many isotropic etchants for pure germanium exist. Common to all of these is an oxidizer, such as HNO_3 or H_2O_2, and a complexing agent to remove the oxide, like HF or H_3PO_4. Early studies were made on isotropic germanium etching by solutions such as "Superoxol", a commercially available H_2O_2-HF recipe. More recently, investigations have been made on

15   various combinations of HNO_3, HNO_2, HF, H_2SO_4, H_2SO_2, CH_3COOH, H_2O_2, and H_2O.

In fact, some of these compositions selectively etch germanium or silicon-germanium alloys over silicon, because of differences in the relative oxidation or oxide dissolution rates, but only one etchant exhibits the inverse preference relevant to this project: 100% NH_4OH at 75°C directly attacks polysilicon at 2.5 μm/hr but polygermanium at only 660 Å/hr. Unfortunately, the

20   selectivity is only about 37, the etch rate for silicon is impracticably slow, and the etch is isotropic, which limits its usefulness in micromachining.

Previous results with heavy concentrations of germanium in silicon are likewise

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discouraging with respect to silicon micromachining. Shang et al., J. Electrochem. Soc. 141, p.

507 (1994), incorporated herein by reference, obtained a selectivity of 6 for relaxed, dislocated

$Si_{0.7}Ge_{0.3}$:B (10^{19} cm^{-3}) in a KOH-propanol-$K_2Cr_2O_7$ aqueous solution. Yi et al., Mat. Res.

Soc. Symp. Proc. 3779, p. 91 (1995), developed a novel NH_4NO_3-NH_4OH etchant with

5   selectivities better than 1000 at 70°C for 10% and higher germanium alloys. The mixture does

not etch pure germanium, but etches pure silicon at 5.67 µm/hr, a weak pace for micromachining

purposes. Both systems are isotropic.

By holding the $Si_{0.7}Ge_{0.3}$:B film under the critical thickness, Shang's team improved the

selectivity in the same KOH-propanol-$K_2Cr_2O_7$ solution to about 40. Narozny et al., IEEE

10   IEDM (1988) 563, were the first to use such a "strain-selective" recipe, but only realized a

selectivity of 20 (for 30% germanium doped with 10^{18} cm^{-3} boron) and a sluggish etch rate of

1.5 µm/hr at room temperature for pure silicon.[26] Although the results of Shang et al. and

Narozny et al. might have simply been from the well-established etch-stop ability of boron,

Godbey et al., Appl. Phys. Lett. 56, p. 374 (1990), achieved a selectivity of 17 with undoped

15      $Si_{0.7}Ge_{0.3}$. None of the articles on strain-selective etchants offer an explanation for the

selectivity.

The anemic etch rate is a grave disadvantage because many MEMS structures can be fairly

large compared to typical VLSI dimensions. Moreover, MEMS structures subjected to strain-

selective etchants would have to be thinner than the critical thickness. However, as a

20   pseudomorphic structure is released and its strain relieved, the selectivity would deteriorate. A

sacrificial strained etch-stop layer could be used, imposing additional process steps and design

constraints, but would at least provide advantages over current oxide/ nitride sacrificial layers:
monocrystallinity can continue above the layer and silicon-germanium's growth selectivity with
respect to oxide adds design/ patterning freedom.

5   The consensus of the research community has been that low concentrations of germanium
have little or no effect on etch stopping in anisotropic etchants like KOH and EDP. Up to 12%
germanium, Seidel et al. detected no significant suppression of etch rate. p++ layers strain-
compensated with 2% germanium showed no remarkable differences from those without
germanium. By implanting germanium, Feijóo et al., J. Electrochem. Soc. 139, pp. 2312-13
(1992), attained a maximum selectivity of 12 to 24 in EDP at 80°C, corresponding to a dose with
10   a peak concentration of about 0.6%.

Finne et al., J. Electrochem. Soc. 114, p.969 (1967), however, observed that $Si_{1-x}Ge_x$
solid solutions with x as small as 0.05 did not etch in an ethylenediamine-pyrocatechol-water
(EPW) solution. This discrepancy may be attributed to the use of {111} wafers, where accurate
measurements are difficult because etching in the <111> direction is very slow. No other
15   information has been reported on germanium-rich alloys in anisotropic media.

Corresponding to the ostensible ineffectiveness of germanium as an etch-stop agent in
most publications, there has been little discussion of the source of the limited selectivity that has
been detected. Seidel et al. cautioned that their model for heavily-doped boron etch stops is not
applicable to germanium because the element is isoelectronic to silicon. They assumed instead
20   that the small reduction of the etch rate is either due to changes in the energy band structure, or
else a consequence of the extremely high concentration of lattice defects such as misfit
dislocations which could act as recombination centers.

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The invention provides a SiGe monocrystalline etch-stop material system on a

monocrystalline silicon substrate. The etch-stop material system can vary in exact composition,

but is a doped or undoped $Si_{1-x}Ge_x$ alloy with x generally between 0.2 and 0.5. Across its

thickness, the etch-stop material itself is uniform in composition. The etch stop is used for

5   micromachining by aqueous anisotropic etchants of silicon such as potassium hydroxide, sodium

hydroxide, lithium hydroxide, ethylenediamine/ pyrocatechol/ pyrazine (EDP), TMAH, and

hydrazine. For example, a cantilever can be made of this etch-stop material system, then released

from its substrate and surrounding material, i.e., "micromachined", by exposure to one of these

etchants. These solutions generally etch any silicon containing less than $7x10^{19}$ cm^{-3} of boron or

10   undoped $Si_{1-x}Ge_x$ alloys with x less than approximately 18. ·

Thus, it has been determined that alloying silicon with moderate concentrations of

germanium leads to excellent etch selectivities, i.e., differences in etch rate versus pure undoped

silicon. This is attributed to the change in energy band structure by the addition of germanium.

Furthermore, the nondegenerate doping in the $Si_{1-x}Ge_x$ alloy should not affect the etch-stop

15   behavior.

The etch-stop of the invention includes the use of a graded-composition buffer between

the silicon substrate and the SiGe etch-stop material. Nominally, the buffer has a linearly-

changing composition with respect to thickness, from pure silicon at the substrate/ buffer interface

to a composition of germanium, and dopant if also present, at the buffer/ etch-stop interface

20   which can still be etched at an appreciable rate.. Here, there is a strategic jump in germanium and

concentration from the buffer side of the interface to the etch-stop material, such that the etch-

stop layer is considerably more resistant to the etchant. For example, the buffer could grade up to

$Si_{0.85}Ge_{0.15}$, then jump to a uniform etch-stop layer of $Si_{0.7}Ge_{0.3}$. Nominally, the composition gradient in the buffer is 5-10% Ge/micron, and the jump in Ge concentration is 5-15 relative atomic percent Ge. The buffer and etch-stop materials are deposited epitaxially on a standard silicon substrate, such as by chemical vapor deposition (CVD) or molecular beam epitaxy (MBE).

5   Note in the above example that the germanium concentration leads to etch stop behavior, and therefore doping concentrations in the etch stop can be varied independently, without affecting etch selectivity.

With respect to the effect of crystalline defects on the etch-stop behavior, in accordance with the invention using $Si_{1-x}Ge_x$ alloys, the influence of defects is minimal. The use of a graded

10   buffer suppresses the threading dislocation density (TDD) in the top etch-stop layer, which leads to a uniform, nearly defect-free $Si_{1-x}Ge_x$ etch stop.

The significance of the jump in concentration(s) at the end of the graded region is that the part must be well defined and dimensions well controlled. Thus, a high selectivity should exist between the top etch-stop layer and the end of the graded region for abrupt, predictable etch-stop

15   behavior. A smooth compositional transition from buffer to etch-stop layer would lead to curved edges and greater dimensional variability in the micromachined part, whereas compositional jumps would yield clean, sharp edges and precise dimensions in the released structure. However, if the jump is too large, e.g., greater than ~20-25 atomic% Ge, the corresponding change in lattice constant, i.e., the lattice mismatch, would create defects.

20   The $Si_{1-x}Ge_x$ etch-stop material system, which can be substituted for heavily boron-diffused layers, broadens the spectrum of available etch-stop materials, including undoped (isoelectronic) materials, thus improving the design flexibility for micromachined structures. For

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example, standard micromachining processes limit the dimensions of silicon sensor structures to a

single uniform thickness. Resonant devices for inertial sensing would benefit considerably from

more flexible design in which the resonators are thinner than the seismic mass. The invention

provides an enabling technology for such a multi-thickness structure. Such a fundamental

5   advantage makes the novel technology widely applicable to the fabrication of MEMS by silicon

micromachining.

A tremendously significant application is the ability to integrate mechanical and electronic

devices on the same material. Replacement of the heavily boron-doped etch stop, which is

incompatible with integrated circuit (IC) requirements, by isoelectronic and/or moderately-doped

10   etch stops of device quality allows concurrent processing of mechanical devices and associated

electronics on the same wafer. Germanium is perfectly miscible in silicon and diffuses much less

readily than dopants and impurities. Alloying with germanium also affords higher carrier

mobilities to the electronic devices.

Furthermore, epitaxy of $Si_{1-x}Ge_x$ alloys is selective with respective to silicon oxide, which

15   facilitates patterning and structuring. In addition, defects do not seem to affect the etch-stop

efficacy of these materials.

In developing the germanium-based etch stops of the invention, standard 3" or 4"

phosphorous-doped (2-4 $\Omega \cdot cm$) or boron-doped (7-10.2 $\Omega \cdot cm$) (001) silicon substrates were

used. The wafers were cleaned for 10 minutes in a piranha bath (3:1 95% H_2SO_4 in water: 30%

20   H_2O_2 in water) and 10 seconds in 4.4% HF and DI water. The substrates were then left in the

load lock (~10^{-8} Torr) of the vertical UHVCVD reactor overnight. On the following day, the

substrates were raised to the lip of the reactor chamber for about two hours to drive off any

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volatiles, organics, and water. Then the wafers were desorbed of whatever oxide remained by

raising them into the 850-900°C reactor chamber for several minutes. A silicon buffer layer on

the order of 1 μm was deposited with SiH_4 while the reactor was brought to process temperature.

Following this preparation procedure each time, the epitaxial structures were grown in the

5   temperature range 750-900°C using SiH_4, GeH_4, 1% B_2H_6 in H_2, and 1% PH_3 in H_2.

KOH and EDP were used in the etching. KOH is a commonly studied etchant , the

simplest and easiest to consider, and relatively easy and safe to use. Although details of absolute

etch rate differ, various anisotropic silicon etchants have behaved consistently. Seidel et al.'s

well-subscribed theory of anisotropic etching is explicitly etchant-nonspecific. Results,

10   discussions, and conclusions regarding anisotropic etching and etch-stopping of silicon are widely

considered to be valid for any anisotropic etchant. Cylindrical etching and patterned oxide masks

were both used to determine the efficacy of Ge concentration on etch rate.

To test the utility of the relaxed epitaxial SiGe etch stops, epitaxial structures were

fabricated: WU_2, WU_3, WU_4, and UHV_17 as shown in FIGs. 1A-1D. FIG. 1A is a

15   functional block diagram of an epitaxial SiGe etch stop structure 100 (WU_2) configured on a

silicon substrate 102. The structure includes a plurality of relaxed graded layers 104 that vary

from $Si_{0.98}Ge_{0.02}$, $5\times10^{20}cm^{-3}$ B at the substrate surface, to the top surface layer of $Si_{0.74}Ge_{0.26}$,

$10^{18}cm^{-3}$ P. The thickness of each layer are provided in μm.

FIG. 1B is a functional block diagram of an epitaxial SiGe etch stop structure 110

20   (WU_3) configured on a silicon substrate 112. The structure includes a plurality of relaxed

graded layers 114 that vary from $Si_{0.99}Ge_{0.01}$ at the substrate surface, to the top surface layer of

$Si_{0.84}Ge_{0.16}$.

FIG. 1C is a functional block diagram of an epitaxial SiGe etch stop structure 120

(WU_4) configured on a silicon substrate 122. The structure includes a relaxed graded layer 124

of $Si_{0.66}Ge_{0.34}$.

FIG. 1D is a functional block diagram of an epitaxial SiGe etch stop structure 130

5   (WU_4) configured on a silicon substrate 132. The structure includes a plurality of relaxed

graded layers 134 that vary from $Si_{0.97}Ge_{0.03}$, $3x10^{15}cm^{-3}$ B at the substrate surface, to the top

surface layer of $Si_{0.66}Ge_{0.34}$, $4x10^{16}cm^{-3}$ B.

The compositional grading is known to considerably relax the superficial epitaxial layer

while effectively suppressing the TDD. The slow grading rate and generous thickness of these

10   epistructures assure a well-relaxed top film. Thus, the graded buffer enables etching experiments

on relaxed, high quality, high germanium content alloys, an etching regime that has never been

accessible before. As discussed heretofore, prior research dealt with pseudomorphic $Si_{1-x}Ge_x$

layers or low concentrations of germanium to minimize dislocations, or heavy germanium alloys

saturated with threading dislocations. Hence, the grading technique permits one to use the

15   intrinsic etch-stop properties of $Si_{1-x}Ge_x$ solid solutions.

Based on the approximate volume of a cross-sectional TEM sample, a single threading

dislocation in a TEM sample represents a TDD of about 10^8 cm^{-2}. FIG. 2 is a cross-sectional

TEM micrograph of structure 110 (WU_3). The top surface is in the upper right direction. The

parallel lines (misfit dislocations) define the graded buffer. No threading dislocations can be

20   found, which confirms high crystalline quality. The blurred vertical bands are "bend contours", an

artifact of TEM, not threading dislocations.

The absence of threading dislocations in FIG. 2 confirms that structures 110 (WU_2), 120

(WU_3), and 130 (UHV_17), which were processed in virtually identical fashion, contain very

few defects. TDDs in such relaxed, graded structures have been shown to be in the range of 10^5-

10^6 cm^{-2}. By omitting the graded buffer, structure 120 (WU_4) was intentionally processed to be

significantly imperfect, as verified by FIG. 3. FIG. 3 is a cross-sectional TEM micrograph of

5   structure 120 (WU_4). The top surface is to the right. In contrast to FIG. 2, this film is saturated

with threading dislocations, which confirms poor crystalline quality. The misfit dislocations in all

four of these samples are buried under such a thick overlayer that they cannot possibly affect

etching from the top surface.

Dopant concentrations of structures 100 (WU_2) and 130 (UHV_17) are shown in the

10   graphs of FIGs. 4 and 5 respectively. The dopant concentrations were calculated from the

mobilities of pure silicon and pure germanium, as indicated. Since structure 130 (UHV_17)

contains 30% germanium, the true boron content lies somewhere in between, closer to the pure

silicon line. Regardless, it is clear that the boron doping does not approach the levels needed for

etch stopping. Structure 130 was doped p-type to investigate potential interactions or synergies

15   with germanium that were suppressed in structure 100 by intentional background n-doping.

The characteristics of these materials (top layer) that are relevant to etching are

summarized in the following table.

sample	avg %Ge (EDX)	doping [cm^{-3}]	defect density (TEM)
WU_2	26	10^{18} P (SIMS)	Low
WU_3	17	None	Low
WU_4	34	None	High
UHV_17	30	4×10^{16} B (SRP)	Low

20   Structure 100 (WU_2) was used to identify the critical germanium concentration by

cylindrically etching and to obtain etch rate values by etching from the top surface.

The cylindrical etch results of structure 100 (WU_2), as shown in the graph of FIG. 6A, confirm the etch-stop behavior of germanium and narrowed the threshold germanium concentration to the range of 16-22%. It was ensured that there were no effects from boron by

5   doping the film n-type. The terraces on the left of the graph, defined by the round dots, represent the layers in the epistructure. The left scale reflects the depth of each layer while the right scale relates the nominal germanium concentration of each layer. The arc is the initial groove surface, and the square dots trace the etched surface.

FIG. 6B is a magnification of the left side of FIG. 6A. It is clear that the etch rate

10   increases dramatically somewhere around 18-20% germanium, suggesting that the critical germanium concentration is in that vicinity.

The cylindrical etch results of structure 130 (UHV_17), as shown in the graph of FIG. 7, show the etch accelerating dramatically around 4.8-5 μm depth. The 5% Ge/μm grading rate reasonably assures that the threshold germanium concentration is near 20% germanium. The

15   profiles of each side of the groove are shown. The lower bar marks where the profile begins to deviate from the initial grooved shape. The depth of this point appears to be 4.8-5.0 μm below the top surface.

The results of the etch rate tests using oxide windows are presented in the following table.

wafer	at% Ge	concentration Ge [cm^{-3}]	etch rate [μm/hr]
WU_2	25.6	1.28×10^{22}	0.070
WU_3	16.9	8.45×10^{21}	0.234
WU_4	34.0	1.70×10^{22}	0.040
UHV_17	30.0	1.50×10^{22}	0.133

The etch rate for <100> intrinsic silicon in 34% KOH at 60°C was taken as 18.29 μm/hr from Seidel *et al.* The experimental data for structures 100 (WU_2), 110 (WU_3), 120 (WU_4), and 130 (UHV_17) are shown in the table. Normalized by 18.29 μm/hr, they are plotted in the graph of FIG. 8 along with Seidel et al.'s points.

5   Some features in FIG. 8 should be emphasized. First, there was appreciably greater variability, both up and down, in the individual etch rates of "good" structure 120 (WU_4) pieces than of the other good samples, hence the error bar. A comparison of all the data supports the belief that the considerable surface roughness of structure 120 (WU_4), from lattice-mismatch stress and the high TDD, is probably to blame. Thus, the graded layer has already proven its

10   efficacy since the graded layer samples did not display this problem.

The shape of the new curve very closely resembles that of EDP-boron curve, adding confidence in the new data as well as implying the existence of a universal etch-stop model. In addition, KOH, a more environmentally friendly etch stop than EDP, appears to be a better etch stop with SiGe alloy than EDP with the conventional p++ etch stop.

15   Despite the popular sentiment in the literature, it is indisputable that silicon-germanium alloys with sufficient germanium are exceptional etch stops that rival the most heavily boron-doped materials. Three different etching techniques and two etchant systems, KOH and EDP, conclusively show this. The intersection of the steep portion of the KOH-germanium curve with unity relative etch rate, the so-called "critical concentration" as defined by Seidel et al., appears to

20   be 2×10^{21} cm^{-3}, i.e., 4%, for germanium. Although this value is about 100 times greater than their "critical concentration" for boron, higher selectivities can theoretically be attained with germanium because there are neither solid solubility nor electrical activity limits.

The substantial selectivities obtained from the well-relaxed, low-defect sample structures 100 (WU_2), 110 (WU_3), and 130 (UHV_17) indicate that strain, induced by defects or dissimilar atomic radii, is not principally responsible for etch-stop behavior.

Defects do not play a central role in etch resistance. The excellent results from WU_2,

5   WU_3, and UHV_17, relaxed materials with low TDDs, controvert the speculation that lattice defects serving as recombination centers cause the etch stop behavior with germanium or isoelectronic additives, respectively. Furthermore, a comparison of the etch rate of structure 120 (WU_4) to the KOH- germanium trendline indicates that even a high TDD does not influence etch stopping dramatically (if at all), nor in a predictable fashion.

10   The immediately attractive explanation for germanium's newfound etch-stop potency in silicon is the mechanism outlined by R. Leancu, *Sensors and Actuators*, A 46-47 (1995) 35-37, incorporated herein by reference. For 15-30% germanium, it seems more logical to interpolate from the bulk properties of pure germanium than to postulate only how germanium influences the properties of otherwise pure silicon. That is, one should give the germanium atom just as much

15   credit as the silicon atom, since it is no longer a dopant, but rather an alloying species in the truest sense. Thus, the silicon-germanium alloys in question should show a palpable influence from the etching characteristics of pure germanium, which include a slow rate in KOH.

Keeping this simple chemistry approach in mind, a completely miscible binary system like silicon-germanium would display a linear dependence of etch rate versus alloy composition. Even

20   without etch rate data at high germanium concentrations, including pure germanium, FIG. 8 plainly illustrates that such is not the case. Along the same lines, it is unclear why there would be some critical concentration of germanium for an etch-stop effect if the etch rate is simply a

consequence of chemical structure, i.e., the proportion of each element. In fact, a nonlinear plot and a critical concentration imply that the etch rate is a function of energy band structure rather than chemical structure.

On a related note, FIG. 8 shows that the germanium-KOH curve is remarkably similar in
5   shape, but not necessarily slope, to the boron-EDP curve, which ascribes its shape to the electronic etch-stop theory. It is difficult to imagine that the germanium-KOH data would just happen to resemble the boron-EDP data, based on a completely different model that warns of no applicability to germanium. That is, it is highly improbable that the true etch-stop mechanism for germanium is entirely unrelated to the true mechanism for boron when the shapes agree so well.

10 There are reasons to consider an energy band model to account for the etch-stop behavior in silicon-germanium solid solutions. First, the $Si_{1-x}Ge_x$ data resemble the p++ Si:B data, including the critical concentration and power-law dependence of the remnant etch rate, and the p++ Si:B data is explained well by energy band effects. At these quantities, germanium is known to markedly change the band structure of silicon. Furthermore, two possible mechanisms for the
15 etch stop effect of germanium were defects and energy bands. Defect enhanced recombination can be eliminated due to our graded layer approach. Energy band structure is the only other possibility.

Pure bulk germanium has an energy bandgap, E_g, of 0.66 eV at room temperature, compared to 1.12eV for pure bulk silicon. Hence, the addition of germanium to silicon reduces
20 the bandgap: unstrained $Si_{0.7}Ge_{0.3}$, the situation for samples WU_2, WU_3, WU_4, and UHV_17, has an energy gap of approximately 1.04 eV. Germanium also has a smaller electron affinity, χ, than silicon, 4.00eV versus 4.05eV. Thus, the incorporation of germanium decreases

21

the electron affinity as well. As germanium is added, the shrinking bandgap and electron affinity

reduce the band-bending, the potential well in the conduction band, and the potential barrier in the

valence band.

The height of the potential barrier in the valence band, b, is given by:

5
$$b = (\chi - d) + \tfrac{1}{2}E_g \qquad\qquad [1]$$

for a generic intrinsic semiconductor, where d is the distance of the Fermi level from E=0, the

reference vacuum level. It is understood that the bandgap of $Si_{1-x}Ge_x$ does not change perfectly

linearly with germanium concentration, but it is not known how electron affinity decreases with

increasing germanium content. Nevertheless, if the two functions are approximated as linear, then

10   b is also roughly linearly dependent on germanium concentration.

Adding germanium to intrinsic silicon also increases the amount of equilibrium electrons

and holes, n_i and p_i, respectively, via the decreasing bandgap:

$$n_i = p_i = (N_c N_v)^{\tfrac{1}{2}} \exp\!\left(-\frac{E_g}{2kT}\right) \qquad\qquad [2]$$

where N_c and N_v are the effective density of states in the conduction and valence bands,

15   respectively, k is Boltzmann's constant, and T is temperature. To simplify the description, N_c and

N_v will be assumed to be constant and equal to the values for pure silicon. Again, if E_g's

dependence on germanium concentration is considered linear, then p_i is exponentially related to

germanium concentration.

The increased p_i increases the passivation reaction. For the intrinsic situation, it is

20   assumed that the well/barrier is not sharp enough to allow tunneling. This is especially true for

$Si_{1-x}Ge_x$, with the shallower barrier. Furthermore, the inversion layer at the surface is n-type.

22

Then the supply of holes to the passivation reaction is h, the amount of holes from the bulk that

overcome the potential barrier thermally. Thus, h is a Boltzmann activated process:

$$h = p_i \exp\left(-\frac{b}{kT}\right) \qquad [3]$$

Since p_i is exponentially dependent on germanium content while b is linearly related, h is

5   overall exponentially related to germanium concentration. This can easily be seen by substituting

expressions [1] and [2] into [3], yielding:

$$h = (N_c N_v)^{\frac{1}{2}} \exp\left(\frac{-E_g - \chi + d}{kT}\right) \qquad [4]$$

where E_g and χ are linearly dependent on germanium content. If a critical hole concentration

exists for interrupting the etch process, then a critical germanium concentration will be observed.

10   The potential barrier in the valence band increases as the Fermi level moves closer to the

valence band, but the hole concentration is significantly increased by p-doping. In fact, the two

effects exactly offset each other. In the extrinsic case, the equilibrium hole concentration, p, is

defined as:

$$p = n_i \exp\left(\frac{\dfrac{E_g}{2} - E_F}{kT}\right) \qquad [5]$$

15    $E_g/2$-E_F is precisely the change in b when the material is doped. Then, when expression [5] is

substituted for p_i in equation [3], $E_g/2$-E_F exactly cancels the change in b in expression [3]. Thus,

with nondegenerate doping, the value of h never changes from:

$$h = n_i \exp\left(-\frac{b'}{kT}\right) \qquad [6]$$

23

where b_i is the height of the barrier in the intrinsic material. Thus, a great advantage of the SiGe etch stop is that the etch selectivity depends only on Ge concentration.

Test structures of structure 110 (WU_3), completely undoped material, were fabricated and probed. The structure 110 (WU_3) did not provide the 'hardest' etch stop available with

5   SiGe alloys because the germanium concentration (15-17%) was near the concentration when etch stop selectivity starts to decrease. The results were very promising as shown in FIG. 9. FIG. 9 is a photograph of a top view of a micromachined proof mass 900. Even at these low Ge concentrations, etched parts like the proof mass in FIG. 9 are possible. Higher Ge concentrations in the uniform layer (30%) result in extremely hard etch stops, with selectivities approaching

10   1000:1.

It is apparent from cylindrical and top surface etching with EDP and KOH and actual structures micromachined in EDP that relaxed silicon-germanium alloys with sufficient germanium are exceptional etch stops. Selectivities as high as 1000, corresponding to 34% germanium, have been obtained in KOH for the <100> direction. Neither strain nor defects are responsible for

15   these results. High defect density does not influence the etch rate of $Si_{1-x}Ge_x$ dramatically. A plot of relative etch rate versus germanium concentration follows the same shape as p++ Si:B data, including a critical concentration and a power-law dependence of the remnant rate. The etch stop behavior in relaxed SiGe alloys is correlated to changes in band structure, which are solely connected to Ge concentration.

20   The extremely high etch selectivities achieved with the SiGe etch stop material system of the invention have immediate applications in forming semiconductor/oxide structures. One method of forming silicon on insulator is to bond a Si wafer to another Si wafer that is coated

with silicon dioxide. If one of the wafers is thinned, then a thin layer of Si on silicon dioxide/Si is created. Such structures are useful in low power electronics and high speed electronics since the Si active layer is isolated from a bulk Si substrate via the silicon dioxide layer.

The main disadvantage of this process is the difficulty in thinning one side of the silicon
5   substrate-silicon dioxide-silicon substrate sandwich. In order to have high reproducibility and high yield, the entire wafer must be thinned uniformly and very accurately. Buried etch stops have been used with little success. Even buried, thin layers of strained SiGe have been used, but as mentioned earlier these etch demonstrate etch selectivities <<100, and therefore are not sufficient. The relaxed SiGe alloys of the invention are ideally suited for this type of etch stop. By bonding a
10   structure 1000 of a graded SiGe layer 1004 and a uniform composition layer 1006 on a silicon wafer 1002 to a structure 1008 having a silicon wafer 1010 coated with silicon dioxide 1012, the etch-stop of the invention can be used to create a very uniform relaxed SiGe alloy on silicon dioxide, which in turn is on a silicon wafer. This process is shown schematically in FIG. 10.

Once the structures are bonded through, for example, annealing, the silicon substrate 1002
15   and graded layer 1004 are selectively etched away. The finished structure 1014 is a SiGe-on-insulator substrate. It will be appreciated that the structure 1008 can also be a bulk insulating material, such as glass or a glass ceramic.

An entire new materials system from which to make highly effective etch stops has been developed. The new system offers many advantages over current technologies. Germanium is
20   isoelectronic to and perfectly soluble in silicon, and hardly diffuses in it. The deposition of silicon-germanium is selective with respect to oxide. Defects do not weaken the etch-stop efficacy. The etch-stop material can be completely undoped, and according to the proposed band structure

25

model, nondegenerate doping does not influence the etch-stop behavior. This affords incredible

utility and design flexibility, especially to integration with microelectronics. To this end,

germanium would even afford higher carrier mobilities.

Although the present invention has been shown and described with respect to several

5   preferred embodiments thereof, various changes, omissions and additions to the form and detail

thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

CLAIMS

1   1. A monocrystalline etch-stop layer system for use on a monocrystalline silicon substrate,

2   said system comprising a graded layer of $Si_{1-x}Ge_x$ and a uniform etch-stop layer of $Si_{1-y}Ge_y$.

1   2. A monocrystalline etch-stop layer system for use on a monocrystalline silicon substrate,

2   said system comprising a buffer layer graded up to approximately $Si_{0.83}Ge_{0.17}$ and a uniform etch-

3   stop layer of approximately $Si_{0.7}Ge_{0.3}$.

1   3. A method of fabricating a monocrystalline etch-stop layer on a silicon substrate

2   comprising:

3   depositing a graded buffer layer of $Si_{1-x}Ge_x$ on said silicon substrate; and

4   depositing a uniform etch-stop layer of $Si_{1-y}Ge_y$ on said graded buffer layer.

1   4. A method of fabricating a monocrystalline etch-stop layer on a silicon substrate

2   comprising:

3   depositing a buffer layer grade up to approximately $Si_{0.83}Ge_{0.17}$ on said silicon substrate;

4   and

5   depositing a uniform etch-stop layer of $Si_{0.7}Ge_{0.3}$ on said graded buffer layer.

1   5. A method of micromachining an integrated device comprising:

2   depositing a graded buffer layer of $Si_{1-x}Ge_x$ on a silicon substrate;

3   depositing a uniform etch-stop layer of $Si_{1-y}Ge_y$ on said graded buffer layer;

4   etching portions of said silicon substrate and said graded buffer layer in order to release

5   said etch-stop layer; and

6   processing said released etch-stop layer.

1   6. A method of fabricating a semiconductor structure comprising:

2   depositing a graded buffer layer of $Si_{1-x}Ge_x$ on a first substrate;

3   depositing a uniform etch-stop layer of $Si_{1-y}Ge_y$ on said graded buffer layer;

4   bonding said uniform etch-stop layer to a silicon dioxide film provided on a second

5   substrate; and

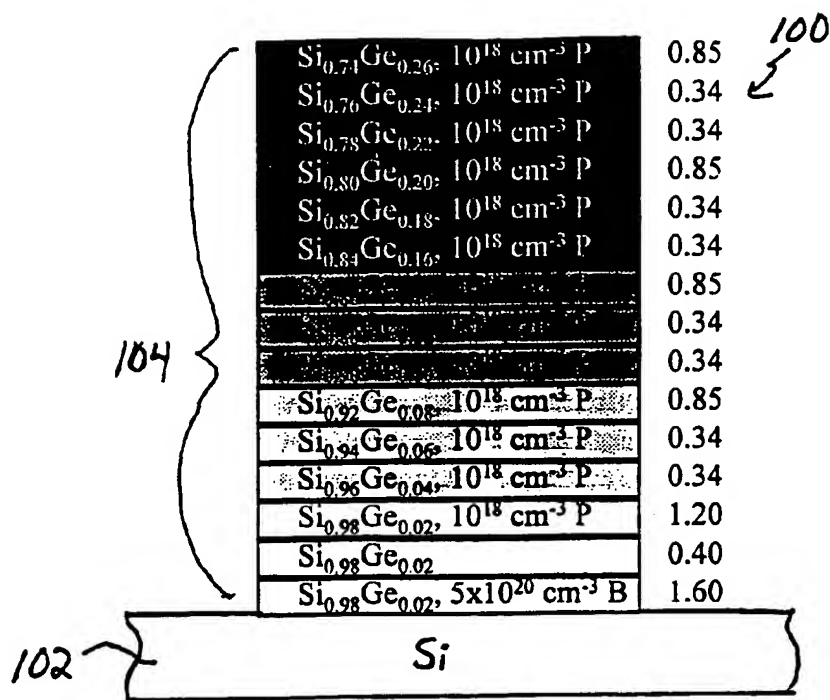6   removing said first substrate.
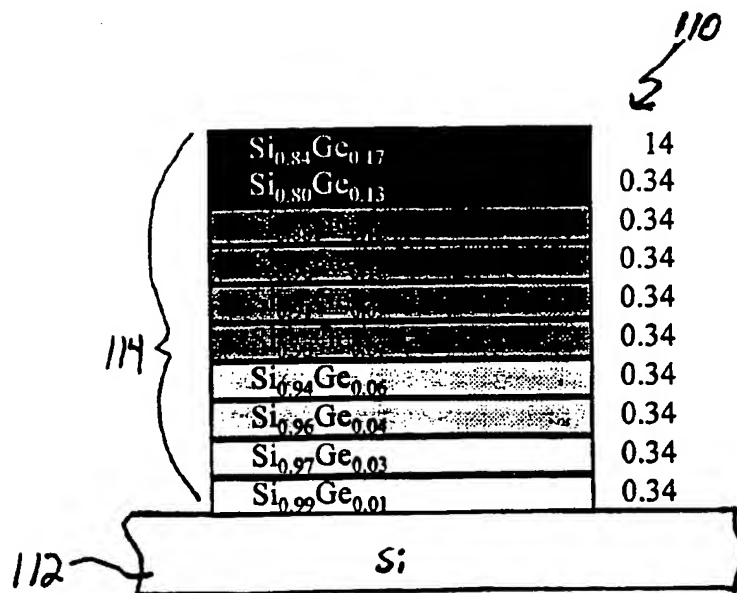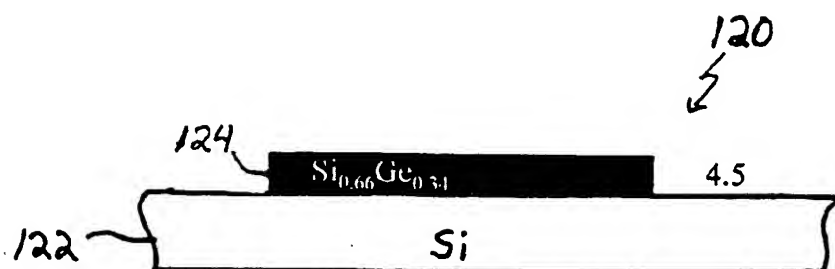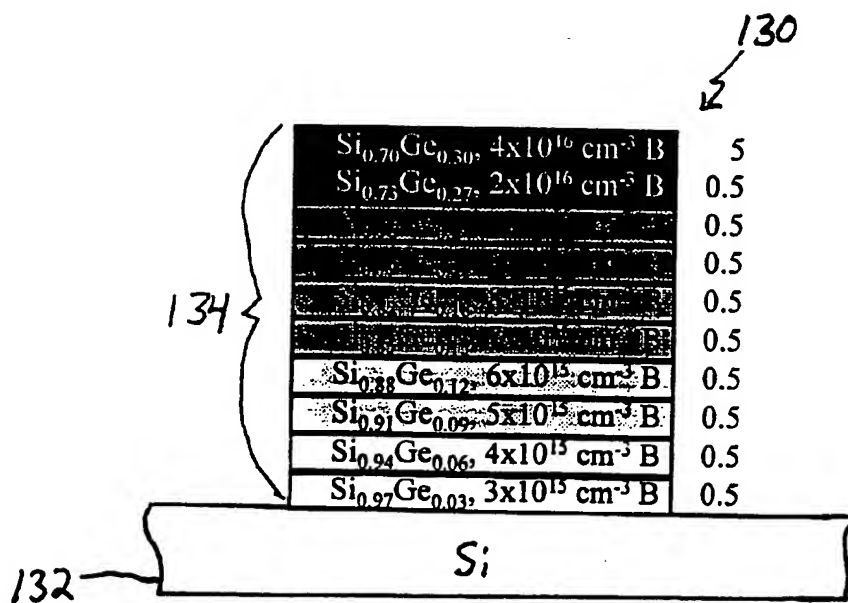
$Si_{0.74}Ge_{0.26}$, 10^{18} cm^{-3} P	0.85	100
$Si_{0.76}Ge_{0.24}$, 10^{18} cm^{-3} P	0.34	
$Si_{0.78}Ge_{0.22}$, 10^{18} cm^{-3} P	0.34	
$Si_{0.80}Ge_{0.20}$, 10^{18} cm^{-3} P	0.85	
$Si_{0.82}Ge_{0.18}$, 10^{18} cm^{-3} P	0.34	
$Si_{0.84}Ge_{0.16}$, 10^{18} cm^{-3} P	0.34	
	0.85	
	0.34	
	0.34	
$Si_{0.92}Ge_{0.08}$, 10^{18} cm^{-3} P	0.85	
$Si_{0.94}Ge_{0.06}$, 10^{18} cm^{-3} P	0.34	
$Si_{0.96}Ge_{0.04}$, 10^{18} cm^{-3} P	0.34	
$Si_{0.98}Ge_{0.02}$, 10^{18} cm^{-3} P	1.20	
$Si_{0.98}Ge_{0.02}$	0.40	
$Si_{0.98}Ge_{0.02}$, 5×10^{20} cm^{-3} B	1.60	

104

Si

102

FIG. 1A

$Si_{0.84}Ge_{0.17}$	14	110
$Si_{0.80}Ge_{0.13}$	0.34	
	0.34	
	0.34	
	0.34	
	0.34	
$Si_{0.94}Ge_{0.06}$	0.34	
$Si_{0.96}Ge_{0.04}$	0.34	
$Si_{0.97}Ge_{0.03}$	0.34	
$Si_{0.99}Ge_{0.01}$	0.34	

114

Si

112

FIG. 1B

120

124

| $Si_{0.66}Ge_{0.34}$ | 4.5 |

122 — Si

FIG. 1C

130

$Si_{0.70}Ge_{0.30}$, 4×10^{16} cm^{-3} B	5
$Si_{0.73}Ge_{0.27}$, 2×10^{16} cm^{-3} B	0.5
	0.5
	0.5
	0.5
	0.5
	0.5
$Si_{0.88}Ge_{0.12}$, 6×10^{15} cm^{-3} B	0.5
$Si_{0.91}Ge_{0.09}$, 5×10^{15} cm^{-3} B	0.5
$Si_{0.94}Ge_{0.06}$, 4×10^{15} cm^{-3} B	0.5
$Si_{0.97}Ge_{0.03}$, 3×10^{15} cm^{-3} B	0.5

134

132 — Si

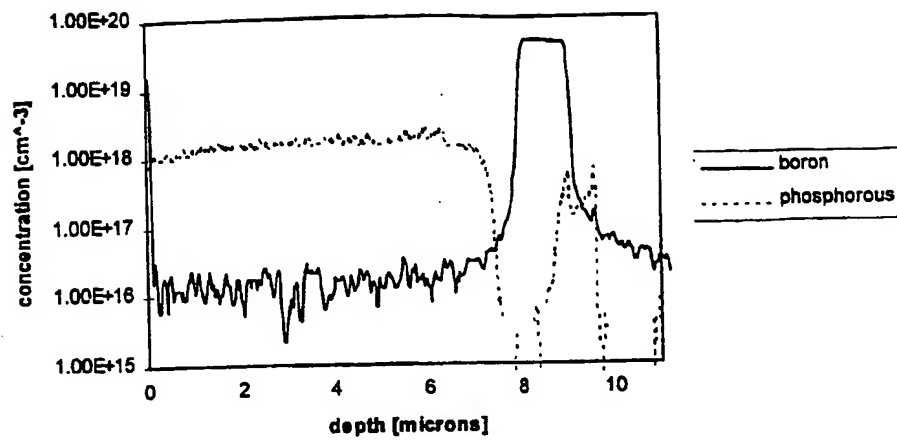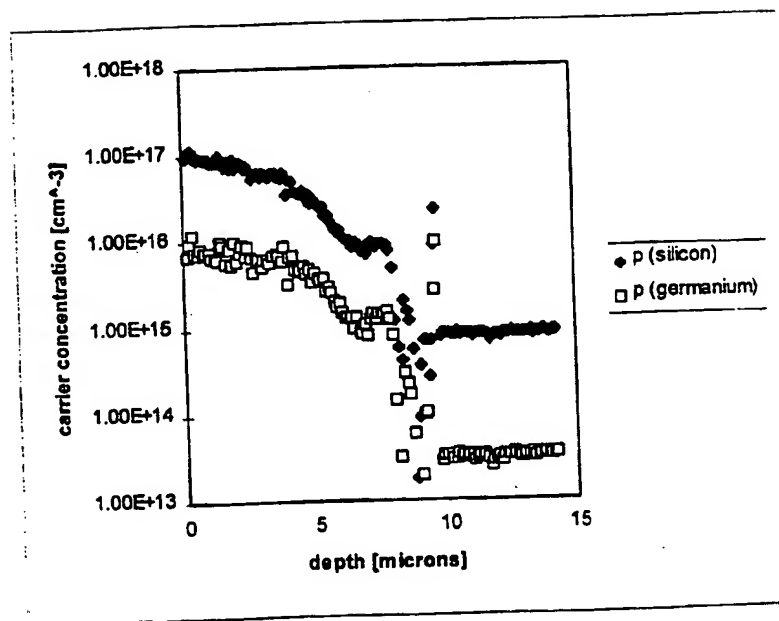## FIG. 1D

_____ 1.5 μm

FIG. 2
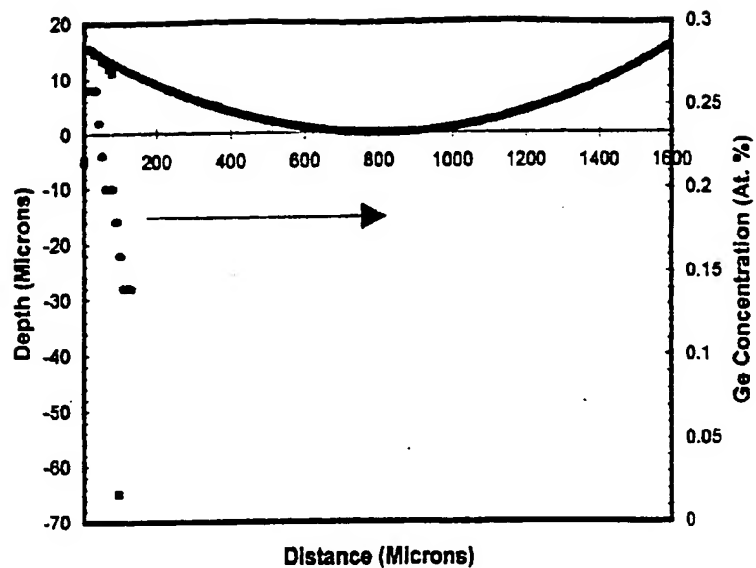
threading
dislocations

silico
subst.

___ 1.3 μm

FIG. 3

FIG. 4

FIG. 5

FIG. 6A

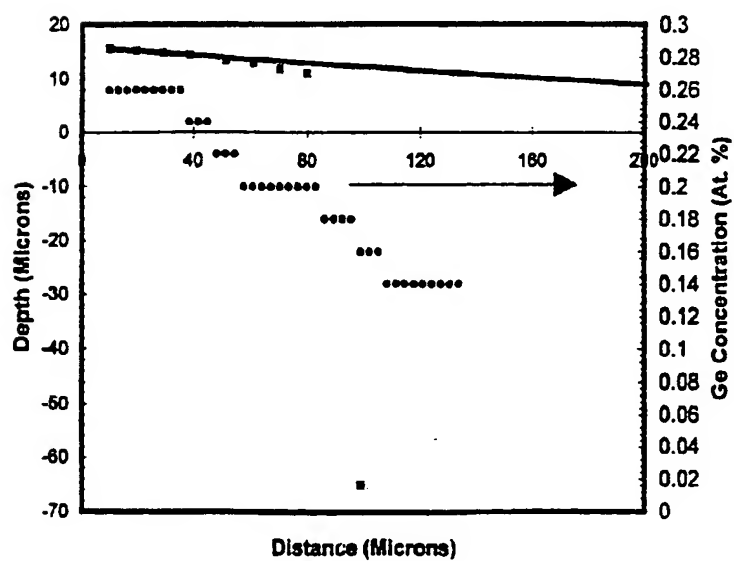FIG. 6B
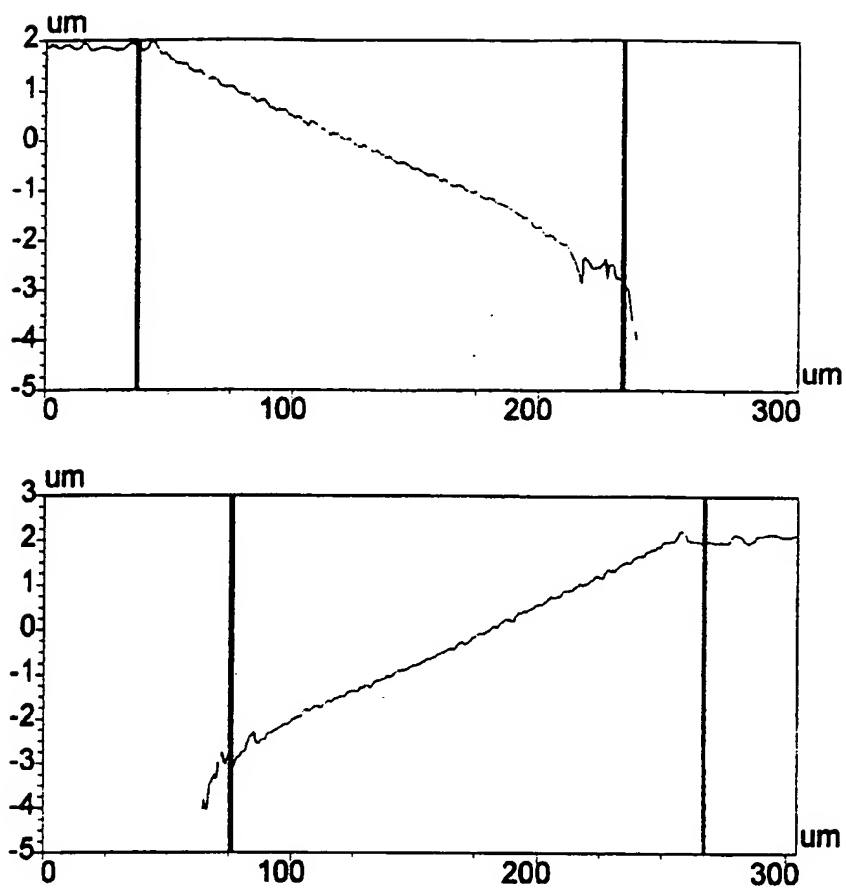
FIG. 7
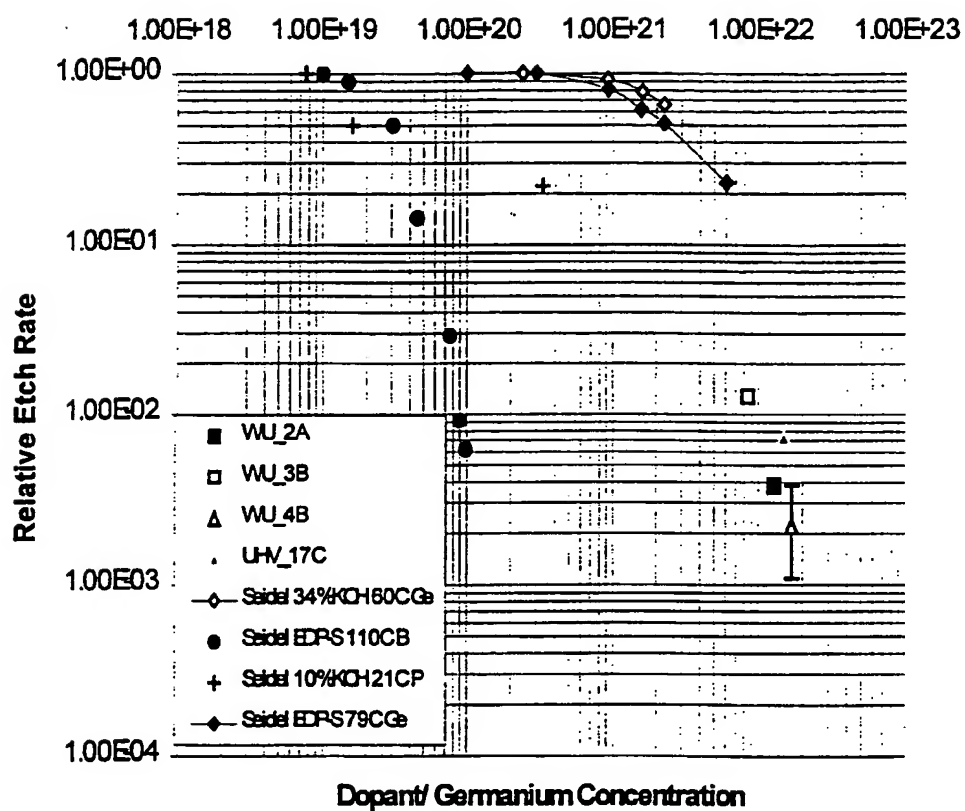
FIG. 8

900
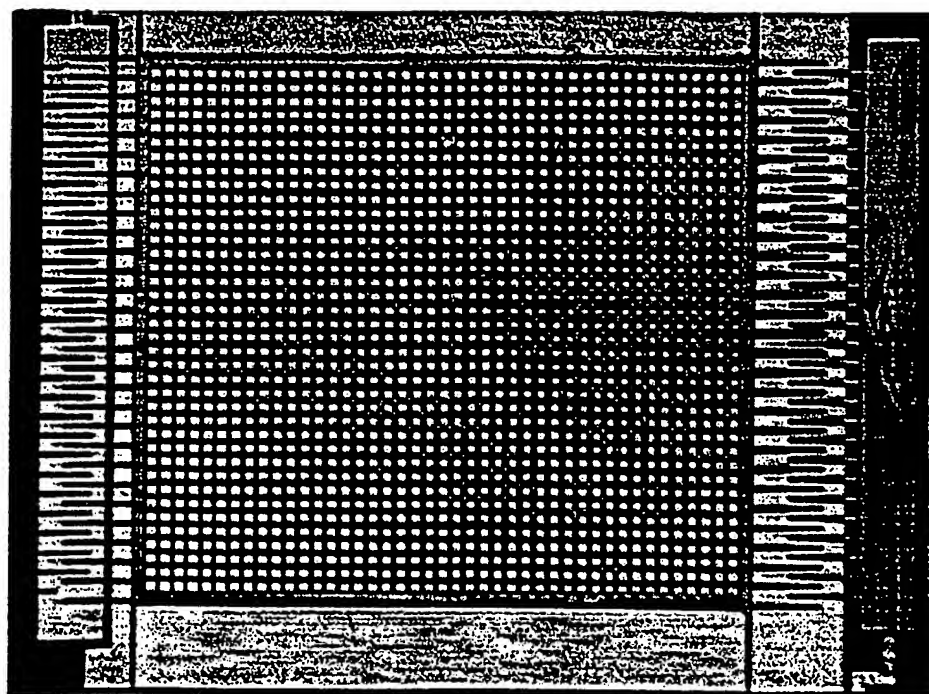
FIG. 9
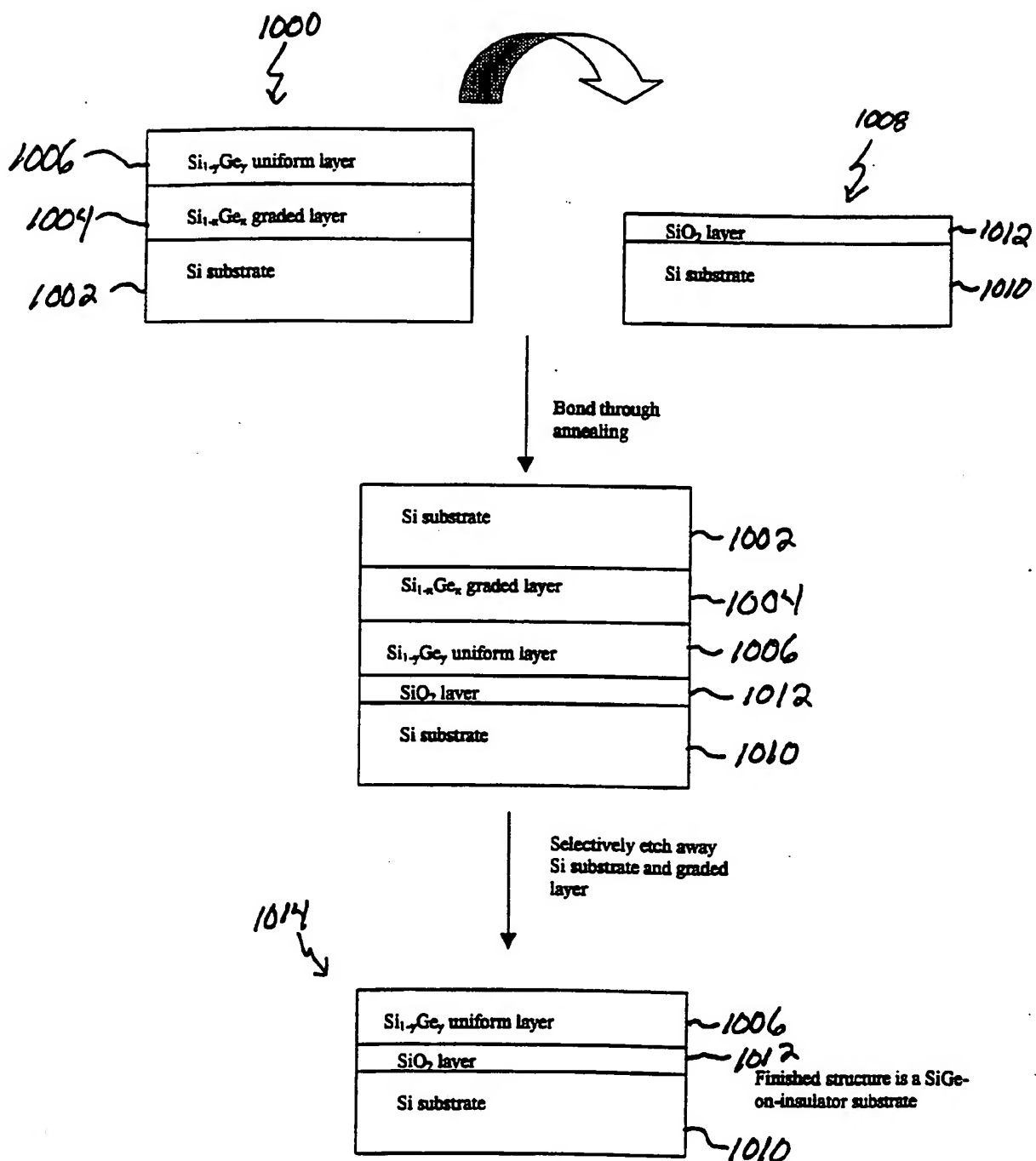
1000

1006 — | Si$_{1-y}$Ge$_y$ uniform layer |
1004 — | Si$_{1-x}$Ge$_x$ graded layer |
1002 — | Si substrate |

1008

| SiO$_2$ layer | —1012 |
| Si substrate | —1010 |

Bond through
annealing

Si substrate	—1002
Si$_{1-x}$Ge$_x$ graded layer	—1004
Si$_{1-y}$Ge$_y$ uniform layer	—1006
SiO$_2$ layer	—1012
Si substrate	—1010

Selectively etch away
Si substrate and graded
layer

1014

Si$_{1-y}$Ge$_y$ uniform layer	—1006
SiO$_2$ layer	—1012
Si substrate	—1010

Finished structure is a SiGe-
on-insulator substrate

FIG. 10

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H01L21/306

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FEIJOO D ET AL: "Epitaxial Si-Ge etch stop layers with ethylene diamine pyrocatechol for bonded and etchback silicon-on-insulator" JOURNAL OF ELECTRONIC MATERIALS, vol. 23, no. 6, June 1994 (1994-06), pages 493-496, XP002111024 ISSN: 0361-5235	1,3
A	the whole document --- -/--	2,4,6

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 August 1999	16/08/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Köpf, C

INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	FITZGERALD E A ET AL: "Totally relaxed Ge(x)Si(1-x) layers with low threading dislocation densities grown on Si substrates" APPLIED PHYSICS LETTERS, vol. 59, no. 7, 12 August 1991 (1991-08-12), pages 811-813, XP000233762 ISSN: 0003-6951 the whole document	1,3
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A	US 5 413 679 A (GODBEY DAVID J) 9 May 1995 (1995-05-09) column 3, line 26 - column 5, line 50	1-5
P,X	BORENSTEIN J T ET AL: "New ultra-hard etch-stop layer for high precision micromachining" PROCEEDINGS OF THE 1999 12TH IEEE INTERNATIONAL CONFERENCE ON MICRO ELECTRO MECHANICAL SYSTEMS (MEMS); ORLANDO, FL, USA, 17 - 21 January 1999, pages 205-210, XP002111025 IEEE, Piscataway, NJ, USA	1,3
P,A	the whole document	2,4,5

1

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			JP	4506587 T	12-11-1992
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US 5413679	A	09-05-1995	NONE		